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A NOMOGRAPHIC AID FOR USE IN DETERMINING THE PERFORMANCE OF HF GROUND ANTENNAS,

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SUMMARY

A nomogram is presented for the calculation of quantities such as free-space loss and receiving antenna gain, required in determining the performance of HF ground antennas when the properties of the calibrating transmitter and its associated antenna are known. An example of the method of using the nomogram is given.

Departmental Reference: Rad-Nav 15

CONTENTS

1 INTRODUCTION

In assessing the performance of HF (3-30MHz) aircraft-ground communication links one of the key components requiring quantification is the performance of the antenna at the ground terminal. One method of measurement that has been found to give promising results is the flying of a transmitter and associated half-wave dipole suspended from a helicopter. By this means it is possible to obtain a radiating element having a known radiation pattern and a known power density. Thus by carefully controlling the flight-path of the helicopter it is possible to determine, from measurements of the received power, the gain and directivity characteristics of the ground antenna.

Since the measured properties of the ground antenna are more readily compared with that of an isotropic antenna it has been found very convenient to use the concept of free space attenuation. To assist in the rapid calculation of free-space attenuation and the subsequent determination of either the antenna gain or the power received by the antenna a combination nomogram has been produced.

2 THE NOMOGRAMS

2.1 The free-space loss, L_{FS}, nomogram

The free-space loss, L_{FS}, in decibel shown is given by (A-7) in the Appendix as

$$L_{FS}(\mathrm{dB}) = 32.45 + 20 \log f + 20 \log d \qquad (1)$$

where f is in MHz and d the slant range between the transmitting and receiving antennas is in kilometres.

The nomogram for equation (1) is shown as the three inner stems of Fig.1.

From expression (A-6) in the Appendix we see that

$$L_{FS}(\mathrm{dB}) = 10 \log P_T G_T + 10 \log (G_R/P_R) \qquad (2)$$

where P_T and P_R, the powers at the transmitting and receiving antennas respectively, are in watts

and G_T and G_R, the antenna gains relative to isotropic antennas, are numerical ratios.

Expressing P_T and P_R in decibel with respect to 1 watt (dBW) and G_T and G_R in decibel we can rewrite equation (2) as

$$L_{FS}(dB) = P_T(dBW) + G_T(dB) + G_R(dB) - P_R(dBW) \quad . \qquad (3)$$

Thus a further nomogram for L_{FS} can be produced. However by making L_{FS} the common factor, the two nomograms each having three stems can be combined into a single nomogram having only five stems of which the central stem for L_{FS} is common (see Fig.1).

For the particular nomographic applications envisaged, G_R is initially assumed to have the value of unity (0dB). Thus when L_{FS}, P_T and G_T are known the indicated value of P_R obtained from the nomogram will differ from the measured value of P_R, the difference being the value of G_R.

2.2 Calibration of the nomogram stems

In accordance with ICAO recommendations[1] the scale for the slant-range distance, d , is calibrated in international nautical miles as well as in kilometres, the international nautical mile being defined as 1852 metres.

The P_TG_T stem has been calibrated both in dBW and in milliwatts. The G_R/P_R stem has basically been calibrated in dBW but for practical convenience a scale in decibel with respect to 1μV(dBμV) has been added so that measured values of received signal, E_R, can be quickly entered. The latter calibration depends upon the assumptions that the receiving antenna is perfectly matched to the receiver input and that the receiver has an input resistance of 50 ohms.

An expression relating P_R(dBW) and E_R(dBμV) is given by equation (A-9) in the Appendix, viz.

$$E_R(dB\mu V) - 137dB = P_R(dBW) \quad .$$

Therefore the dBμV calibrations on the E_R scale should, strictly, be negative in sign for $50G_R/E_R^2$ to be mathematically identical to G_R/P_R. However to avoid confusion when entering the values of E_R obtained directly from the calibrating generator, the signal values are shown with a positive sign.

2.3 Example of the application of the nomogram

Given $f = 8MHz$, $d = 4n$ mile

$P_T = 250mW$, $G_T = 1.5dB$ and $E_R = 70dB\mu V$ when the receiver input resistance is 50 ohms.

Determine G_R.

Step 1 Using the three inner stems enter the values for f and d and read the value of L_{FS}, 67.9dB from the central stem.

Step 2 Using the P_TG_T stem and noting that $P_T = 250mW$ corresponds to -6dBW and adding $G_T = 1.5dB$, enter the total value of $P_TG_T = -4.5dBW$ on the left hand stem.

Step 3 Enter on the central stem the value of L_{FS}, 67.9dB obtained from step 1. Then by using a straight-edge between the P_TG_T, L_{FS} values already obtained, read out on the E_R scale the value shown 64.5dBμV.

Step 4 The value of G_R is found by taking the difference between the value obtained from the nomogram, 64.5dBμV, and the measured value 70dBμV i.e. $G_R = 5.5dB$.

If the transmitted and received powers P_T and P_R and the antenna gains G_T and G_R are accurately known then the nomogram could be used, in a similar manner to that given above, for the comparison of the measured and the theoretical values of the free-space loss, L_{FS}.

Cautionary note concerning the use of the nomogram for the determination of the receiving antenna gain, G_R.

It should be emphasized that it is only when the path-loss conditions are known to be those of 'free-space' that this method of determining the receiving antenna gain is valid.

Appendix

DERIVATION OF EXPRESSIONS FOR THE POWER RECEIVED BY AN ANTENNA AND THE FREE-SPACE LOSS BETWEEN TWO ANTENNAS

(see section 2.1)

A.1 An expression for the power received by an antenna

The power P_R received by an antenna[2] is

$$P_R = \frac{P_T G_T}{4\pi d^2} A_R \quad \text{watt} \tag{A-1}$$

where A_R is the effective area in square metres of the receiving antenna and

$$A_R = \frac{G_R \lambda^2}{4\pi} \quad \text{square metres.} \tag{A-2}$$

Thus from equations (A-1) and (A-2)

$$P_R = P_T G_T G_R (\lambda / 4\pi d)^2 \quad \text{watt} \tag{A-3}$$

where P_T is the transmitted power in watts
G_T is the numerical gain of the transmitting antenna
G_R is the numerical gain of the receiving antenna, the gains G_T and G_R being relative to that of an isotropic antenna
λ is the wavelength in metres
d is the distance between the two antennas in metres.

Changing from wavelength to frequency, f, in hertz using $c/f = \lambda$ where c is the velocity of propagation of light we obtain

$$P_R = P_T G_T G_R (c/4\pi f d)^2 \quad . \tag{A-4}$$

A.2 An expression for the free-space loss, L_{FS}

Re-arranging (A-4) we can obtain

$$(4\pi fd/c)^2 = P_T G_T G_R / P_R \tag{A-5}$$

where $(4\pi fd/c)^2$ is defined as the free-space loss, L_{FS}, between the transmitting and receiving antennas.

Taking logarithms of both sides of expression (A-5)

$$L_{FS}(\mathrm{dB}) = 20 \log (4\pi fd/c) = 10 \log P_T G_T + 10 \log (G_R/P_R) \tag{A-6}$$

thus providing two expressions for L_{FS} which have simple nomographic solutions. If in (A-6) the frequency f is expressed in megahertz and the distance d in kilometres we can, after substituting for c the velocity of propagation[3] (299 792.5km/s), obtain one expression for L_{FS} as

$$L_{FS}(\mathrm{dB}) = 32.45 + 20 \log f(\mathrm{MHz}) + 20 \log d(\mathrm{km}) \quad . \tag{A-7}$$

The alternative expression for L_{FS} is

$$L_{FS}(\mathrm{dB}) = P_T(\mathrm{dBW}) + G_T(\mathrm{dB}) + G_R(\mathrm{dB}) - P_R(\mathrm{dBW}) \tag{A-8}$$

where dBW is used to denote dB with respect to 1 watt.

The received power, P_R, can be expressed in terms of the voltage, E_R, measured across the input resistance R_I of the receiver, assuming that the receiving antenna is perfectly matched to the receiver input. Thus if $R_I = 50\Omega$ we have $P_R = E_R^2/50\Omega$ where P_R and E_R are in watts and volts respectively. Expressing P_R in dBW and E_R in dB wrt $1\mu V (1 dB\mu V)$

$$P_R(\mathrm{dBW}) + 120\mathrm{dB} + 17\mathrm{dB}(\mathrm{wrt}\ 1\Omega) = E_R(\mathrm{dB}\mu V) \quad . \tag{A-9}$$

SYMBOLS

c	velocity of propagation
d	slant-range distance
f	frequency of transmitted signal
E_R	voltage measured across receiver input resistance, R_I
G_R	gain of receiving antenna relative to an isotropic antenna
G_T	gain of transmitting antenna relative to an isotropic antenna
L_{FS}	free-space loss
P_R	power received by the antenna at the ground station
P_T	power of airborne transmitter
R_I	receiver input resistance
λ	wavelength of transmitted signal

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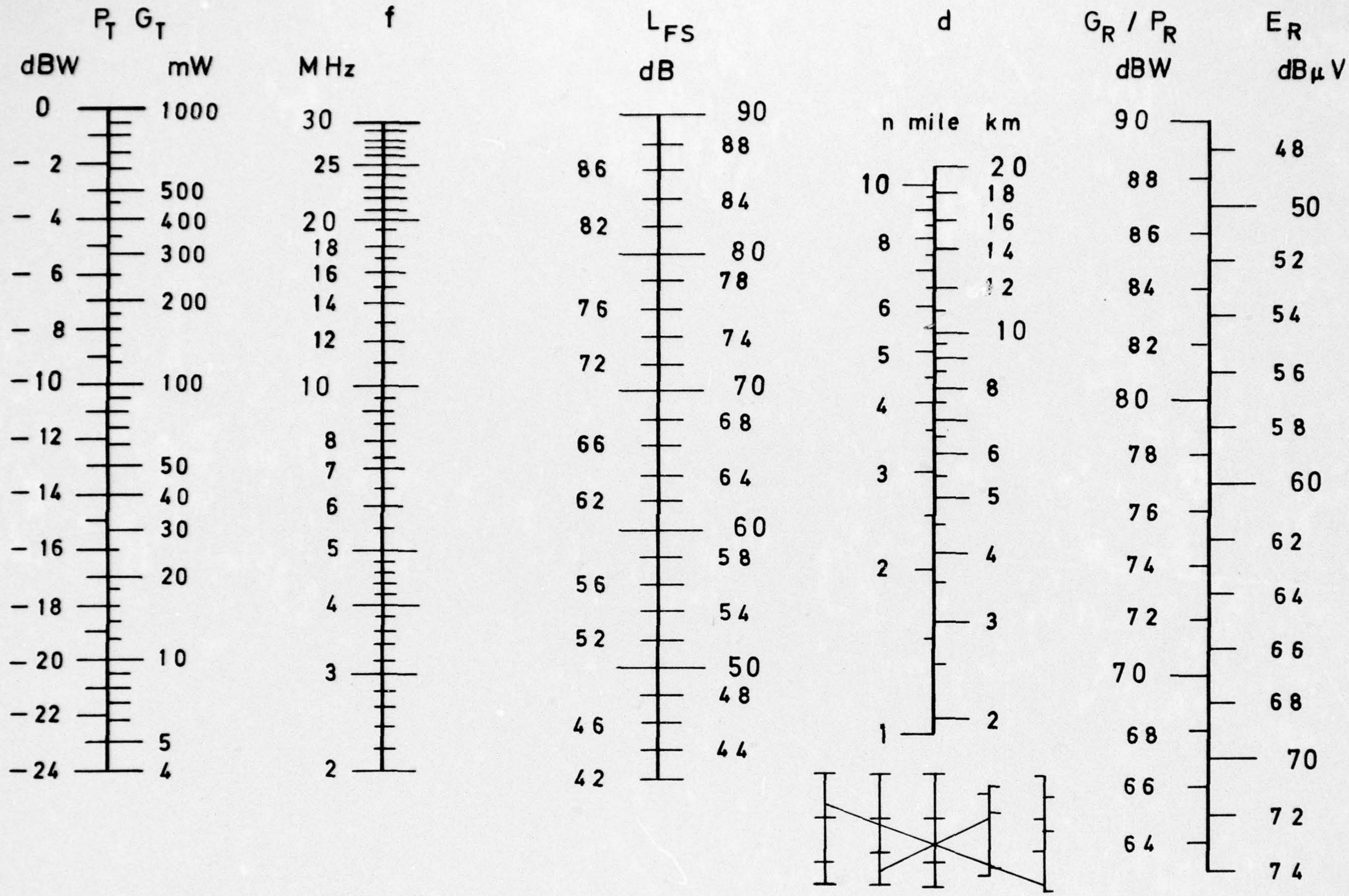

$L_{FS} = (4\pi\, fd/c)^2 = P_T G_T G_R / P_R$ and $E_R^2 / 50\Omega = P_R$

Fig. 1 Free-space loss nomogram.

Fig.1